STATUS REPORT OF THE INTRODUCED PINE SAWFLY OUTBREAK IN THE SOUTHERN APPALACHIANS 1982

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ABSTRACT

The introduced pine sawfly, Diprion similis (Hartig), was first discovered in the southern Appalachians in 1977. Since then, it has been detected in two distinct outbreaks, covering a total of 10,000 square miles in North Carolina, Tennessee, and Virginia. This report evaluates the insect's current status and discusses the results of the application and research program initiated in 1979.

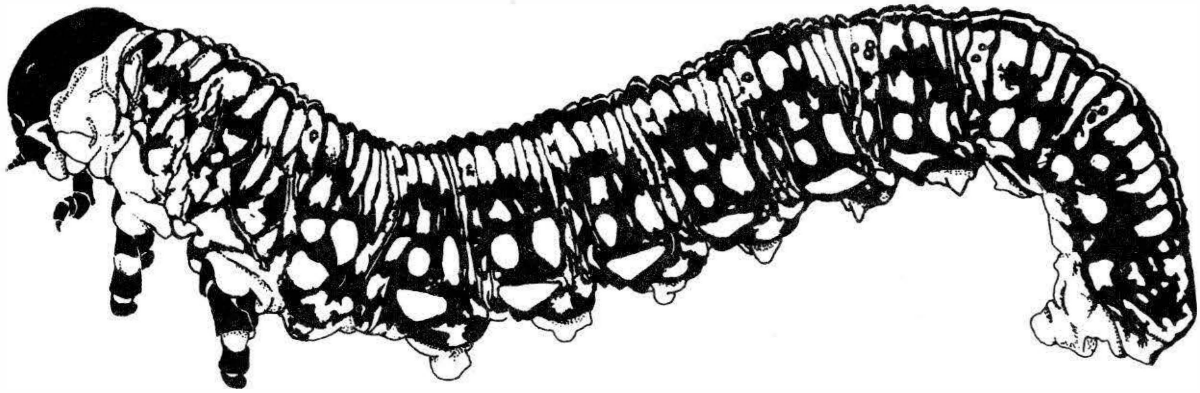
INTRODUCTION

The introduced pine sawfly, Diprion similis (Hartig), was first discovered in New England in the early 1900's (Britton, 1915). It has since become established across the Northern Tier States to Wisconsin and across southern Canada. In 1977, an infestation on eastern white pine, Pinus strobus (L.), was detected near Linville Falls in Avery County, North Carolina (Drooz, et al., 1979). Since that time, the insect has been detected over a 10,000 square mile area in North Carolina, Tennessee, and Virginia.

The favored host of this defoliator is eastern white pine. Repeated defoliation of white pine has resulted in growth loss, dieback of the upper crown, and total tree mortality. Trees weakened by defoliation are also more susceptible to secondary invasion of insects and diseases. With the volume of eastern white pine in this area exceeding 1 million m^3 (35 million ft^3), the insect poses a serious threat to an important component of the southern Appalachian forest. In addition, white pine is highly valued as an aesthetic species for scenic and recreation areas. It is also an important species of numerous Christmas tree plantations throughout the South.

In 1979, a research and applications program was initiated by Forest Pest Management and Forest Insect and Disease Research to study evaluate. and suppress the introduced pine sawfly. This report discusses what has been learned and the insect's current status.

TECHNICAL INFORMATION



Insect

Introduced pine sawfly, Diprion similis (Hartig).

Hosts

In the southern Appalachians, eastern white pine is the favored and most severely damaged host. Results of the 1980 study on host suitability indicate that shortleaf and Virginia pine can be attacked, but they are not considered threatened (Huber, 1981). It appears that loblolly and slash pine are unsuitable as hosts for the sawfly.

Type of Damage

The larvae damage host trees by defoliating them. Larvae are phototactic and feed in the upper portion of the crown, so that defoliation is more visible toward the top of the crown. First generation larvae prefer to feed on the previous year's needles. However, when the population is large, newly forming needles may also be consumed. This type of defoliation may cause the tree to fail to set buds for the next year's growth, causing dieback and eventual tree mortality. Second and third generation larvae feed on the present year's foliage, which has hardened, as well as the remaining foliage from the past year. Larvae will feed on the bark of twigs when all of the tree's foliage has been consumed.

Complete defoliation in 1979 did not lead to tree mortality in most cases, since the trees were able to refoliate in the spring of 1980. However, a number of trees in several locations were attacked by a branch canker fungus, Valsa kunzei, which girdles the branch, causing dieback and tree mortality. Trees infected with V. kunzei died rapidly in the spring of 1980. Secondary insects then entered the trees and caused further degrade in wood quality.

In 1981 and 1982 some mortality occurred in trees which had suffered extensive defoliation in 1979. Valsa kunzei did not appear to be associated with this mortality. These individual, large, white pines have died throughout the center of the infestation, where sawfly populations and defoliation were greatest. It is speculated that these dying trees may have been infected with a root rot fungus. The stress of heavy defoliation and several years of drought could have weakened the trees to a point where the fungus invaded and eventually killed the tree.

Life History

The sawfly overwinters as a prepupa within the cocoon. As springtime temperatures increase, the sawfly pupates and adults begin emerging. The extended period of emergence for the first generation leads to overlap of the life stages during the growing season. Adult males locate females by a sex pheromone the female emits. The proportion of males to females may be greater than 1:1, since unmated females are able to produce and lay fertile eggs which develop into males. Soon after emergence, the adults mate and the female lays the eggs serially in a slit in the needle. The eggs hatch in 10 to 14 days, and the tiny larvae feed gregariously on the old needles. As the larvae mature, they become solitary feeders. The larvae mature in four to six weeks; the males going through five instars, females six. The larvae stop feeding and molt into a final non-feeding instar, characterized by gray heads rather than the characteristic shiny black head capsule of the feeding larvae. The "gray-head" spins a cocoon. Cocoons can be found on almost any surface, but mostly on the leaves and stems of undergrowth and the host tree.

SEASONAL DISTRIBUTION

In 1979, a non-destructive sampling method was developed to monitor the life stages of the introduced pine sawfly. In 1980 and 1981, the sawfly population in Avery County, North Carolina, was sampled weekly from May through October to determine the seasonal history and number of generations per year for this insect in the southern U.S. A partial life table was also developed from the 1980 data (Huber, 1981).

The 1980 seasonal history of the introduced pine sawfly in western North Carolina is pictured in Figure 1. Usually, distinct peaks in the seasonal distribution of a multivoltine insect represent separate generations. Three peaks in adult emergence and subsequent egg laying were observed. However, it is most likely that the first two peaks represent the emergence of the first generation, and the peak in late July represents the second generation. The first two peaks could not indicate separate generations because there was insufficient time between the first observations of eggs and the second peak in adult emergence for development of second generation adults. In addition, very few late instars were observed prior to the second emergence of adults. Therefore, the adults must have developed from prepupae which had been in diapause from the previous summer.

The reason for the two peaks in the first generation can be correlated with weather conditions during May. The decrease in adult emergence corresponded to a rainy period of about one week (Fig. 2). Heavy rains and early spring cold periods have been reported to cause mortality of adult sawflies and

Figure 1.--A diagrammatic representation of the seasonal history of the sawfly in Avery County, North Carolina. The width of each band indicates the relative abundance of the life stage over time.

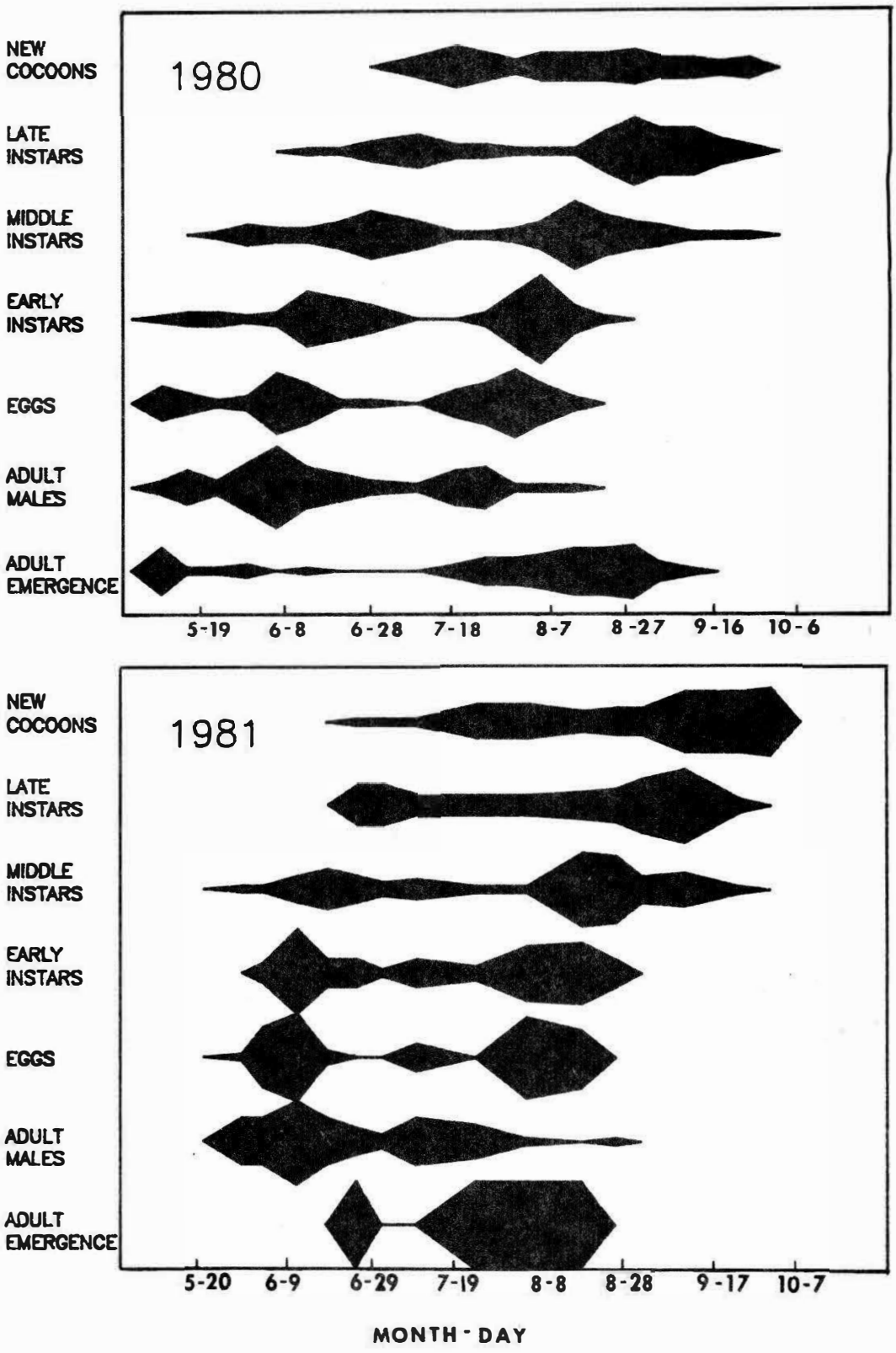
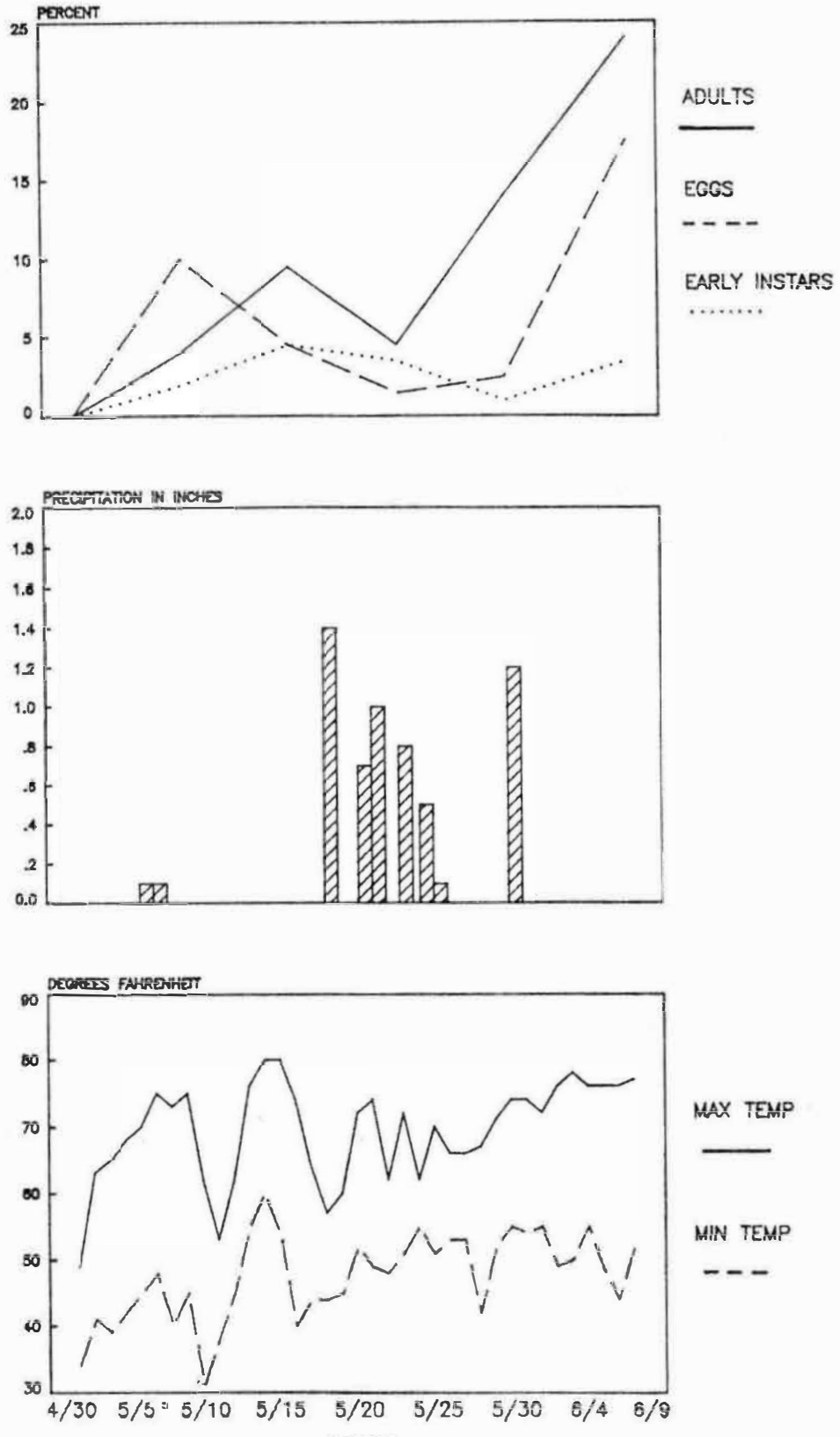


Figure 2.--A comparison of the temporal distribution of early first generation sawfly life stages with ambient air temperature and precipitation.



larvae (Coppel et al., 1974). Larvae are able to survive slow changes in temperature, but sudden drops in temperature can cause mortality. Larvae and adults can also be dislodged from the branches and die during heavy rain storms. The rain, combined with fluctuating temperatures, may have suppressed emergence or killed newly emerged adults, as well as early feeding instars. When the rain stopped, adult emergence resumed.

The introduced pine sawfly has the potential to have three generations per year; however, we observed only two in 1980. First generation adult sawflies began emerging in early May. Adult emergence and egg laying continued until the end of June. First generation larvae fed from early June through July. These larvae spun cocoons and completed development from mid-June to mid-July. In early July, second generation adult sawflies began emerging. Eggs were laid until mid-August and peak egg laying occurred around August 1. Second generation larvae fed during August and September. Newly spun cocoons were found throughout the month of September.

In sampling the 1981 sawfly population, two generations were also observed (Fig. 1). First generation adults emerged and laid eggs in May. By mid-July, larvae had finished feeding and were spinning cocoons. Second generation adults emerged in early July, and eggs could be found until mid-August. Larvae fed throughout August, and by the end of September, most larvae had spun cocoons.

A partial life table was constructed to determine the amount of mortality which occurred at each life stage in 1980. Three life tables are presented in Table 1. Table 1A and 1B represent the two peaks in the first generation, and Table 1C represents the second generation. In Table 1A, mortality was greatest during the egg and mid-instar (3 and 4) life stages. The development of this early portion of the first generation was probably curtailed by fluctuating temperatures and rain, and this is reflected in the partial life table. Tables 1B and 1C, which represent the first and second generations, indicate that the highest losses occurred during the early (1 and 2) and late (5 and 6) instars. High mortality during the early instars is common. Coppel et al. (1974) reported that "the greatest proportion of larval mortality usually occurs during the first two stadia", and adverse host and weather conditions are usually responsible for the mortality (Britton and Zappe, 1918; Tsao and Hodson, 1956). The high apparent loss observed for late instars is a reflection of the low number of cocoons observed on the sample branches. Sawfly larvae tend to move either to the top of the tree crown or to vegetation beneath the tree to spin cocoons (Coppel et al., 1974). By sampling from mid-crown, we probably did not get a true representation of the number of larvae which actually reached the prepual stage (within the cocoon). Therefore, the high "mortality" figure for late instars can probably be attributed to migration of the larvae and spinning of cocoons outside of the sample zone.

DISTRIBUTION

Methods

During the winter of 1980, several thousand prepupal cocoons were collected and reared out to obtain virgin females. Females were frozen upon emergence. When the desired number of sawflies was acquired, the pheromone was

Table 1.--A partial life table for the 1980 Diprion similis (Hartig) population in Avery Co., North Carolina. Numbers refer to the total of 45, 1 meter branch samples.

Age interval x	No. alive at start of x lx	No. dying during x dx	Factor causing dx a/	dx as a % of lx 100 qx
(A) First Generation				
Egg	437	245	low temperatures	56.06
Larva				
1st & 2nd instars	192	66		34.38
3rd & 4th instars	126	96	fluctuating temperatures and heavy rainfall	76.19
5th & 6th instars	30	7		23.33
Prepupa in cocoon	23			
(B) First Generation				
Egg	852	161	desiccation	18.90
Larva				
1st & 2nd instars	691	398		57.60
3rd & 4th instars	293	51	predation	17.41
5th & 6th instars	242	92	predation, parasitism, and migration	38.02
Prepupa in cocoon	150			

Table 1.--con't

Age interval x	No. alive at start of x lx	No. dying during x dx	Factor causing dx a/	dx as a % of lx 100 qx
(C) Second Generation				
Egg	1377	140	desiccation	10.17
Larva				
1st & 2nd instars	1237	774		62.57
3rd & 4th instars	463	15	predation	3.24
5th & 6th instars	448	318	predation, parasitism, and migration	70.98
Prepupa in cocoon	130			

a/ These factors were observed as possible causes of mortality. The percent mortality figures cannot be attributed entirely to these factors.

extracted by the Southeastern Forest Experiment Station, at Research Triangle Park, according to a method described by Jewett (1978).

The amount of pheromone placed in dental wicks for use as a lure is expressed as a fraction of the material obtained from the total number of sawflies used for the extraction. A sawfly equivalent, or "SFE", is defined as that fraction representing a single female (Casida et al., 1963). Each dental wick contained 10 SFE.

Wicks were placed in the center of Pherocon® II traps (Zoecon Corp., Palo Alto, Calif.). Since the leading edge of the infestation had been delineated in 1980, only areas outside were surveyed in 1981. During peak sawfly emergence in May and June of 1981, the traps were placed at predetermined locations. After two weeks, the traps were examined and the number of male sawflies caught was recorded. Those trap locations with positive (at least one male trapped) results closest to a negative (no males trapped) trap were moved at 5-mile increments toward the negative location and checked periodically. If the trap was again positive, it was moved again until a negative trap was recorded. In this manner, the edge of the infestation was plotted. Due to a limited supply of pheromone, only the southern infestation was surveyed.

Figure 3 shows the southern area infested in 1980 and the area infested in 1981.

Results

In 1980, the southern infestation covered 15,500 square kilometers (approximately 6,000 sq. mi.); in 1981, the sawfly infested approximately 24,000 square kilometers (approximately 10,000 sq. mi.). The major increase occurred in a southwest to northeast direction. This is probably due to the distribution and concentration of native white pine in that direction. In areas east and west of the infestation, white pine nears the edge of its range.

The rapid growth of the infestation was surprising. However, since the pheromone attracts males from only a limited distance, areas with very low populations may not have been detected. Therefore, areas which were negative in 1980 may, in fact, have been infested; and, likewise, areas undetected in 1981 are likely to exist and will be located as sawfly populations build to some detectable level. It is likely that eventually the entire native range of eastern white pine will become infested.

Due to the low sawfly population levels, and therefore the lack of virgin females, future pheromone extraction and trapping will be done on a limited basis only.

PARASITISM

During the summer of 1979, parasite releases for control of the introduced pine sawfly were initiated. In April of 1980, a Parasite Rearing Lab was established at Linville Falls, N.C., for the augmentation of Mondontomerus dentipes and the introduction of Dahlbominus fuscipennis. Initially, a total of 12 release sites were established.

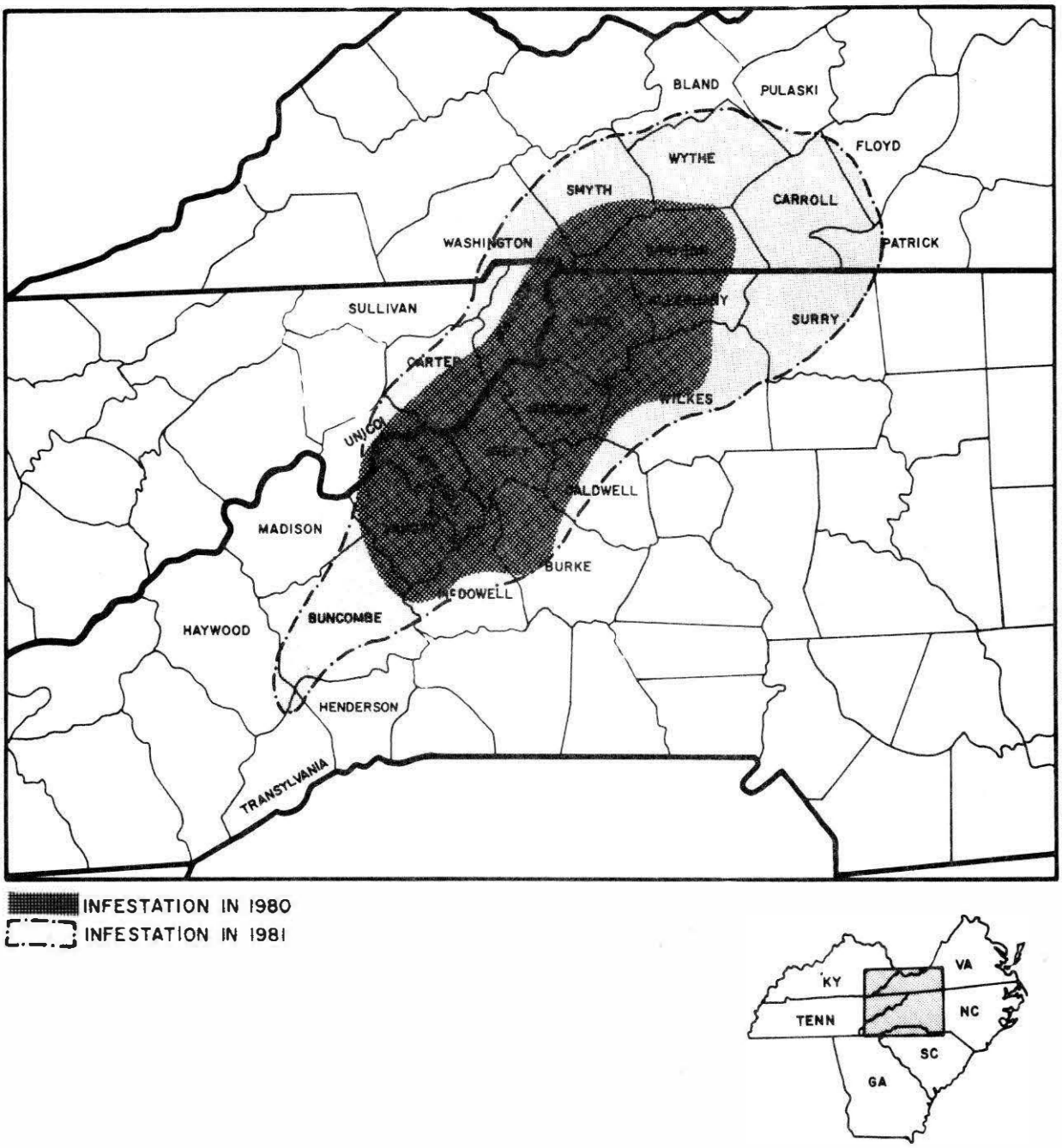


Figure 3-- Distribution of the introduced pine sawfly for 1980 and 1981.

These sites were monitored before and after parasite liberation. Monitoring consisted of cocoon collections from progressive generations, and the percent parasitism by species was determined. Table 2 presents a listing of parasite species recovered and their percent occurrence within the Avery County, N.C., infestation. Figure 4 indicates the success of M. dentipes in reducing sawfly populations and, therefore, defoliation. The decrease in 1981 parasitism is due to the collapse of the sawfly populations within the sample collection area the preceding generation.

In 1981, releases were begun in additional areas where sawfly populations were high and in areas at the advancing edge of the infestation, as determined by pheromone trapping.

By the summer of 1982, sawfly populations became so low as to make cocoon collections for the continued rearing of cocoon parasites difficult. In the spring of 1982, with no further reports of damage, the last of the cocoon parasites were released at the advancing edge. Further parasite work is now concentrated on sawfly egg parasites.

The establishment of an egg parasite(s) is very desirable, since it attacks the life stage before the damaging larval feeding stage, thereby technically preventing defoliation one generation before any of the other known parasites are able to. In addition, the establishment of egg parasites may provide long term stability and reduce the severity of future outbreaks.

In cooperation with the Commonwealth Institute of Biological Control, Delemont, Switzerland, three species of sawfly egg parasites were obtained from Europe. They are the Tetracampid, Dipriocampe diprioni (Ferriere), and the Eulophids, Chrysomotomyia formosa (Westwood) and C. ruforum (Krausse). Initial free releases have so far been limited, but a laboratory colony has been established, and additional releases will be made in 1983.

AVIAN PREDATION

Many insectivorous birds have received attention due to their apparent role as mortality agents of forest insect pests (Coulson et al., 1979). The roles of vertebrate predators as controlling factors in large scale insect outbreaks is now better recognized, and as Otvos (1979) has stated, birds act as direct mortality agents of insect pests, as well as having the capability of indirect control.

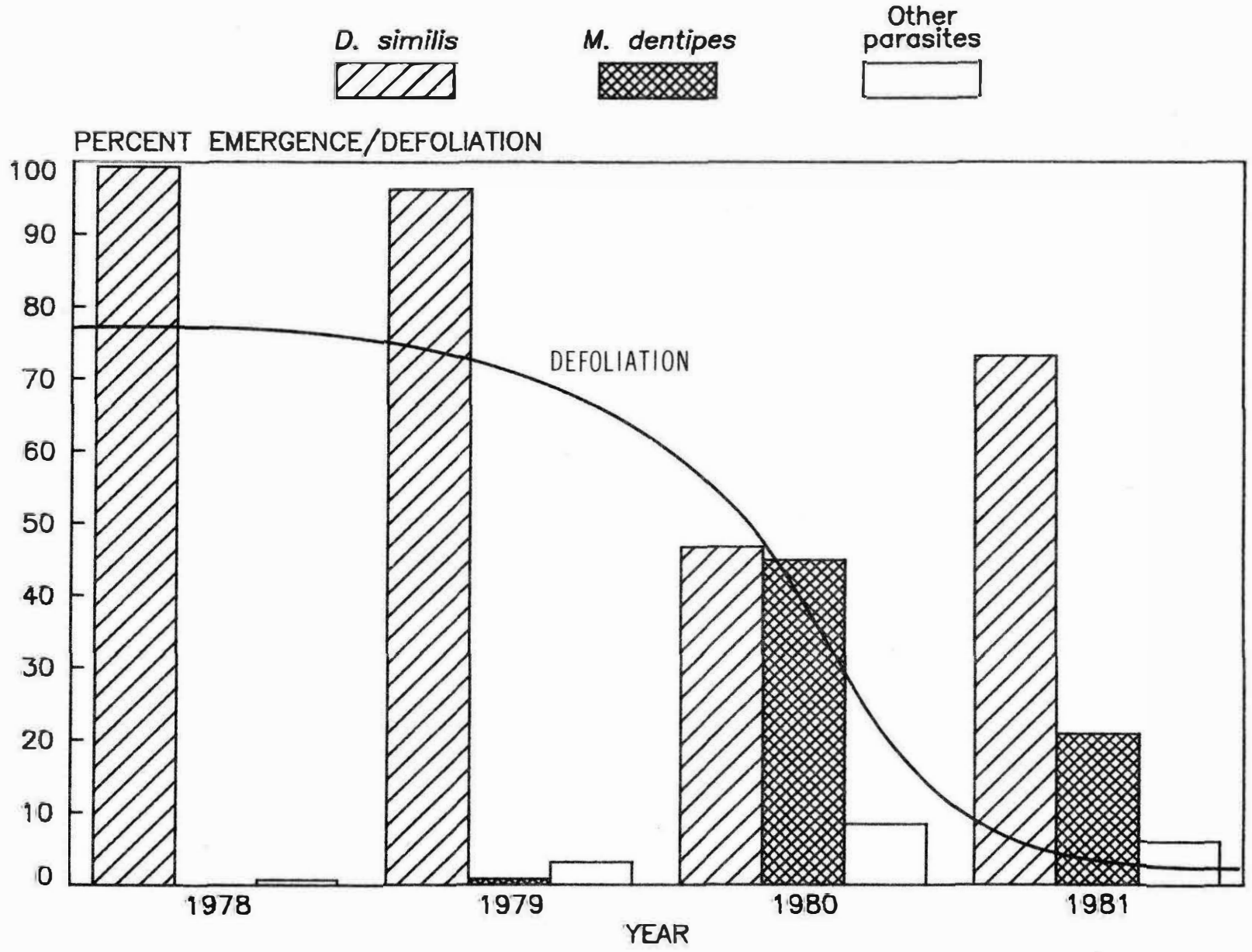
From July 1980 to August 1981, a study was conducted to determine what effect, if any, birds had on Diprion similis during the outbreak in Avery County. The focus of the study was on the cocoon lifestage of the insect. Coppel et al. (1974) states that natural mortality during the cocoon stage is of primary significance in the limitation of sawfly populations. Aside from some field studies in Wisconsin, little literature exist on birds as predators of sawfly cocoons. Black-capped chickadees (Parus atricappilus Linnaeus) and downy woodpeckers (Picoides pubescens L.) were found to be the principle predators of sawfly cocoons in Wisconsin (Coppel et al., 1974).

Table 2.--Percentages of insects emerging from Diprion similis cocoons by year.

	1978	1979	1980*	1981
Diprionidae				
Diprion similis (Hartig)	99.25	96.07	46.72	73.10
Ichneumonidae				
Itoplectis conquisitor (Say)				
Delomerista japonica (Cushman)	.25	.45		.99
Exenterus amictorius (Panzer)		.89	.26	3.38
Exenterus nigrifrons (Roh.)	.25		1.84	.08
Gelis tenellus (Say)		.09		
Pleolophus basizonus (Gravenhorst)		.35		1.32
Agrothereutes lophyri (Norton)	.25	.90	.26	.08
Eulophidae				
Dahlbominus fuscipennis (Zetterstedt)			1.84	.16
Eupelimidae				
Eupelmus spongipartus (Foerster)				
Eupellmella vesicularis (Retzius)			.26	
Torymidae				
Monodontomerus dentipes (Dalman)		.80	44.88	20.87
Pteromalidae				
Amblymerus verditer (Norton)			1.05	
Dibrachys covus (Walker)		.45		
Eurytomidae				
Eurytoma pini (Rugbee)			1.31	
TOTAL PARASITISM	.75	3.93	53.28	26.90

* Totals as of September 1980 for total areas monitored.

Figure 4.--Percent emergence of introduced pine sawfly (D. similis), the parasite Monodontomerus dentipes, and other parasites from sawfly cocoons collected from 1978 to 1981; and the amount of sawfly defoliation in each of those years.



Five sample plots of eastern white pine were used in the collection of D. similis cocoons. Cocoons were collected from July 1, 1980 through August 15, 1981 at approximately 6-week intervals. When collections began, it was necessary to describe the physical condition of each cocoon. Most important was the ability to determine which type of predators; i.e., birds, rodents, or insects, had attacked the cocoons. Aside from a brief description by Coppel et al. (1974), very little literature has been written on the appearance of sawfly cocoons after vertebrate predation.

Field and laboratory observations of cocoons revealed distinctive differences between those preyed upon by birds, rodents, and insects. Rodent-attacked cocoons were characterized by very large extraction holes, while those parasitized by insects were easily recognizable by their emergence holes. Cocoons attacked by birds showed three different patterns in their external appearance:

1. Puncture Mark - The most distinctive mark, apparently left as the beak punctures the cocoon and pulls out the larvae.

2. Tear and Flap - When a ripping action of the beak is involved. During extraction, a portion of the cocoon around the extraction hole is left as a small flap.

3. Single Hole - In many instances, a portion of the cocoon, generally a small piece, was removed during extraction, leaving a small hole. It is frequently not circular, but jagged.

From the five study plots established, a total of 33,840 D. similis cocoons were collected. This sample size is large enough to estimate the effectiveness of birds as predators of the sawfly. Cocoons taken from the field were classified, based on external appearance, into five different categories: Normal Emergence (Group 1), Viable (Group 2), Avian Predated (Group 3), Apparent Parasitism (Group 4), and Miscellaneous, which includes all rodent-predated cocoons (Group 5). The total number of cocoons collected and the percentages for each category from the five collection plots are presented in Table 3.

The avian predation percentage of 29.6 suggests that birds were a major factor in pine sawfly cocoon mortality. Of particular significance is plot number five, where 91.5 percent of all those collected were attacked by birds. In this area, birds appeared to be the most important natural mortality agent of sawfly cocoons. The only major difference between this area and the other four collection areas was the extensive hardwood habitat associated with it, which possibly attracted and helped maintain large numbers of predatory birds.

In order to determine if the percentage of those cocoons preyed upon by birds varied from month to month during one year, a one-way analysis of variance of time in months, compared to percent predation, was made. The analysis revealed that there was no significant difference between time and percent avian predation. Therefore, the percent of cocoons preyed upon by birds was not significantly related to the time of the year.

Table 3.--Cocoon collection summary.

	1		2		3		4		5	
	Normal Emergence		Viable		Avian Predated		Apparent Parasitism		Miscellaneous	
Plot Number	Number of Cocoons	Percent of Total	Number of Cocoons	Percent of Total	Number of Cocoons	Percent of Total	Number of Cocoons	Percent of Total	Number of Cocoons	Percent of Total
1	2203	38.7	918	16.1	2330	40.9	190	3.3	52	0.9
2	9330	68.3	1798	13.2	2111	15.5	316	2.3	107	0.8
3	4151	58.2	1613	22.6	1029	14.4	267	3.7	70	1.0
4	1569	53.1	651	22.0	523	17.7	132	4.5	80	2.7
5	254	5.8	80	1.8	4027	91.5	21	0.5	18	0.4
Summary All Plots	17507	51.7	5060	15.0	10020	29.6	926	2.7	327	1.0

Fifty-four species of birds were identified in the entire study area. Ten species, representing 18.5 percent of the total bird species, were observed as predators of pine sawfly cocoons. Of these 10, 7 (70%) were permanent residents in the area. Not all of these birds were important predators of the sawfly. The determination of the principle avian predators was based primarily on two criteria--percent frequency of the species in the area (a measure of relative abundance) and percent predation (a measure of a species frequence as a predator).

Table 4 lists the predatory species by percent frequency and percent predation. From this, it is clear that the two species of chickadees (considered together in all quantitative calculations due to their extreme similarity in appearance and behavior) and the tufted titmouse were by far the most effective predators of pine sawfly cocoons. The chickadees and titmice were major components of the predatory bird populations throughout the year. There is no doubt that sawfly prepupae within the cocoon were an important part of their diets.

As this study, and others, have shown, birds may play a potentially important role in insect pest suppression. The principle predators of the introduced pine sawfly in North Carolina are cavity nesting species. To be able to thrive and reproduce in suitable numbers, they must have proper habitats available. Maintaining and enhancing nesting habitats should be seen as an important consideration in integrated pest management decisions. Conner (1978) and Evans (1978) both have presented management recommendations aimed at non-game bird species. These would include; 1) discontinuing or limiting the removal of dead and dying trees; 2) keeping in mind individual species requirements, such as basal area of trees, as well as vegetation density; and 3) maintaining and enhancing the physical and vegetational features of the landscape.

Habitat manipulation in the form of nesting boxes is a possibility, although more work needs to be done to determine their effectiveness. There is every evidence that maintaining proper habitat for the cavity nesting species involved as predators would be highly beneficial both now and during any subsequent serious outbreaks.

CONCLUSION

Currently, the introduced pine sawfly has returned to a low level population, and no new areas of severe defoliation have been reported in 1982. However, certain individual trees are still declining due to the high populations and defoliation of the past.

The impact plots established in 1979 will continue to be monitored to determine the long term impact the sawfly has had on the area's white pine resource. The final report will be issued in early 1985.

Forest Pest Management will continue with routine surveillance of the population to maintain records on population trends of both the parasites and pests. Work on establishing the egg parasite in the Linville Falls, N.C., area will continue.

Table 4.--Predatory species by percent predation[a/] and percent frequency[b/].

Species	Percent Predation	Percent Frequency
Black-capped Chickadees (Parus atricappilus L.) and Carolina Chickadees (Parus carolinensis Audubon)	44.0	55.0
Tufted Titmouse (Parus bicolor L.)	27.9	31.7
Blue Jay (Cyanocitta cristata L.)	2.3	19.8
Northern Cardinal (Richmondena cardinalis L.)	4.7	8.4
Solitary Vireo (Vireo solitarius Wilson)	4.7	4.0
Hairy Woodpecker (Picoides villosus L.)	4.7	3.0
Downy Woodpecker (Picoides pubescens L.)	4.7	4.0
Chipping Sparrow (Spizella passerina Beckstein)	4.7	3.5
Fox Sparrow (Passerella iliaca Merrem)	2.3	0.5

a/ Total number of times the species was observed feeding on sawfly cocoons/ total number of observations of feeding x 100.

b/ Total number of times the species was observed in all collection plots/total number of times collection plots were visited x 100.

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